

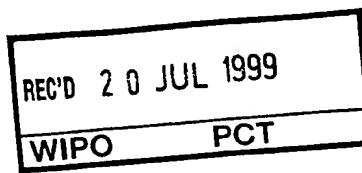
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**Method and apparatus for flame spraying to form a tough coating**

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## METHOD AND APPARATUS FOR FLAME SPRAYING TO FORM A TOUGH COATING

The present invention relates an apparatus and a method of flame spraying to form a coating on flat or curved substrates, for example, either as part of the direct formation of metallic or ceramic coatings such as superconductive or piezo-electric layers or for the production of targets for sputtering magnetrons having coatings which are precursors of such layers. The input material for the flame sprayer may be a liquid solution of soluble compounds (e.g. nitrates) which decompose thermally into ceramic component oxides, liquid slurries of the ceramic components or metal powders, or dry metal or ceramic 5 powders or precursors of the ceramic components, e.g. nitrates, of such powders.

### TECHNICAL BACKGROUND

From EP-A-286 135 it is known to flame spray complex ceramic materials onto a substrate such as a tape to form a superconducting layer. It is recommended to pre-heat 15 the substrate to temperatures above 540°C and to cool the coating slowly. It is further recommended to treat the coating in an atmosphere containing one of the components of the superconducting ceramic. An oxy-acetylene flame is used for the flame spraying.

It is also known from US 5,196,400 to plasma spray a coating onto a target for use in a sputtering magnetron to sputter a Y-Ba-CuO superconductor coating. Deposition 20 of only a thin target coating of 0.5 mm is reported.

The production of superconducting powders using flame spraying is reported in US 5,140,005. An oxy-acetylene flame is used. It is tacitly accepted that the high temperature of the flame changes the stoichiometric ratios of the components and that this has be compensated by increasing the more volatile components in the original 25 mixtures. US 5,045,365 describes a method of cooling a oxy-acetylene flame-sprayed substrate with water which is unsuitable for superconducting ceramics due to the water vapour produced.

It is an object of the present invention to provide an apparatus and a method of flame spraying to form a ceramic coating on flat or curved substrates.

30 It is a further object of the present invention to provide an apparatus and a method of flame spraying to form a thick walled ceramic coating on flat or curved substrates which is structurally sound.

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It is a further object of the present invention to provide an apparatus and a method of flame spraying to form a thick walled coating of a superconducting ceramic material.

5 It is still a further object of the present invention to provide an apparatus and a method of flame spraying suitable for forming a thick walled ceramic coating on flat or curved targets to be used in a sputtering magnetron.

10 It is still another object of the present invention to provide a method of producing a (magnetron) vacuum sputtering target as well as the target itself with improved thermal and electrical conductivity and high mechanical strength using a low cost flame spraying process employing dedicated powder formulations.

#### SUMMARY OF THE INVENTION

The present invention may provide a flame spraying apparatus for spraying materials onto a substrate to produce a coating thereon, comprising: a burner for producing a flame; an inlet for feeding the material to be sprayed through the flame, the flame imparting a temperature to the material to be sprayed of 1500°C or less, preferably 1200°C or less. Preferably the temperature imparted may be a little higher than the melting point of the powder to be sprayed, e.g. 600 to 1000°C for some metal oxides.

15 The present invention may provide a flame spraying apparatus for spraying materials onto a substrate to produce a coating thereon, comprising: a flame spraying gun; and a cooling system for the substrate, the cooling system including a device for bringing a cryogenic fluid into contact with the substrate.

20 The present invention may provide a method of flame spraying materials onto a substrate to produce a coating thereon, comprising:  
25 generating a flame;  
feeding the material to be sprayed through the flame, the flame imparting a temperature to the material to be sprayed of 1500°C or less, preferably 1200°C or less. Preferably the temperature imparted may be a little higher than the melting point of the powder to be sprayed, e.g. 600 to 1000°C for some metal oxides.

30 The present invention may also provide a method of flame spraying materials onto a substrate to produce a coating thereon, comprising:  
generating a flame for spraying the materials; and

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cooling the substrate by bringing a cryogenic fluid into contact with the substrate.

The present invention may also provide a method of flame spraying a superconducting ceramic material or a precursor thereof onto a substrate to produce a coating thereon, comprising: generating a flame for spraying the ceramic material; 5 depositing the coating on the substrate; and during deposition of the coating, cooling the substrate so that the solidified coating thereon has a temperature between room temperature (~25°C) and 150°C, preferably room temperature (~25°C) and 100°C.

The general linking concept between the above methods and apparatus is the reduction of the total heat energy into the flame spraying/coating system.

10 The present invention also includes a method of reconditioning a target for a sputtering magnetron by flame spraying as well as a reconditioned target as made in accordance with the method. The target material or coating is preferably a ceramic coating, in particular a superconducting ceramic coating.

15 The final coating is preferably a metallic or ceramic layer, in particular a superconducting or piezo-electric layer or a precursor thereof. The present invention includes a method of spray drying a liquid to form a powder suitable for flame spraying. The spray dried powder may be sintered. The present invention also includes a manufacturing method for depositing a coating on a substrate comprising the steps of: spray drying a precursor liquid to form a powder and flame spraying the powder to form 20 a coating on a substrate. The substrate may be a target for a sputtering magnetron and the final coating may be sputtered onto a final substrate in the sputtering magnetron. The ceramic powder may be sintered after the spray drying step. The flame of the flame spray gun preferably imparts a temperature to the powder to be sprayed of 1500°C or less, preferably 1200°C or less. Preferably the temperature imparted may be a little higher than 25 the melting point of the powder to be sprayed, e.g. 600 to 1000°C for some metal oxides. During flame spraying the target is preferably cooled by bringing a cryogenic fluid into contact with the target. In particular the cooling device should maintain the solidified coating at a temperature between room temperature (~25°C) and 150°C, more preferably between room temperature (~25°C) and 100 °C.

30 The present invention includes an apparatus for spray drying a liquid to form a powder suitable for flame spraying. The present invention may also include an apparatus for depositing a coating on a substrate comprising:

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- a spray drier for drying a precursor liquid to a powder, and  
a flame sprayer for flame spraying the powder to form a coating on a substrate. The  
substrate may be a target for a magnetron. Additionally, a sputtering magnetron for  
sputtering the final coating onto the final substrate using the target may be provided. The  
flame of the flame spray gun preferably imparts a temperature to the powder to be  
sprayed of slightly above the melting point of the sprayed material. Preferably the  
temperature imparted is 1500°C or less, preferably 1200°C or less. Temperatures of 600  
to 850 °C may be suitable for some metal oxides. In the flame sprayer a cooling system  
for the target is preferably provided, the cooling system including a device for bringing a  
cryogenic fluid into contact with the target. In particular the cooling device should  
maintain the solidified coating at a temperature between room temperature (~25°C) and  
150°C, more preferably between room temperature (~25°C) and 100 °C.

- The above methods may be used, for example, either as part of the direct  
formation of superconductive or piezo-electric layers on the substrate, e.g. a tape, or for  
the production of coatings on targets for use in a sputtering magnetron to sputter a  
superconducting layer onto a final substrate. The present invention may provide oxide  
sputtering targets supporting very high power dissipation thus enabling high sputter  
deposition rates of at least 50 nm/min.

20 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic representation of a flame spraying apparatus in accordance  
with one embodiment of the present invention.

Fig. 2 is a schematic representation of a flame spraying apparatus in accordance  
with another embodiment of the present invention.

25 Fig. 3 is a schematic representation of a spray drying apparatus in accordance with  
another embodiment of the present invention.

DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

- The present invention will be described with reference to certain specific  
embodiments and with reference to certain specific drawings but the invention is not  
limited thereto but only by the claims. In particular, the present invention will mainly be  
described with reference to the deposition of superconductive coatings but the invention

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is not limited thereto but may be used advantageously with other coatings such as metallic coatings, ceramic coatings, particularly those having special properties such as piezoelectric coatings and in particular coatings which contain components which can be degraded by high temperatures or which are more volatile than other components. More particularly the present invention will be described with reference to the manufacture of YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub> superconducting powders and coatings but the invention is not limited thereto but only by the claims.

Fig. 1 is a schematic diagram of the flame spraying apparatus 10 in accordance with a first embodiment of the present invention. A flame spraying gun is represented schematically at 12. The gun 12 may be a commercially available flame spraying gun as for instance available from Sulzer Metco, Westbury, NY, USA or a high velocity oxy-fuel spraying gun available from the same company. The gun 12 may be provided with an air pincher. The gun 12 may be fed with fuel gas in pipe 22, oxygen in pipe 23 and gun cooling air in pipe 24. Additional gases may be supplied to the gun 12 as described for instance in US 5,273,957 or EP-A-413 296. Material to be coated in powder or liquid form, e.g. a dry powder, a slurry of the powder and a liquid or in solution, is fed to the gun via conduit 26 from hopper 21. Gun 12 is mounted on a drive (not shown) which provides the necessary movements of the gun 12 to coat the substrate 19. When substrate 19 is a cylindrical target, for instance, for a rotating cathode magnetron, this may be rotated and the movements of the gun 12 may be simple reciprocating movements parallel to the axis of the target 19. If the substrate 19 is a flat rectangular or circular plate, the movements may be provided by a suitable robot and may be complex, e.g. including rotational cycloidal motions. For rapid deposition several guns 12 may spray the same substrate 19 at the same time.

The fuel gas for the gun 12 may be selected from one of acetylene, propylene, hydrogen or similar fuels but the present invention is not necessarily limited thereto. Particularly preferred in one embodiment of the present invention is a fuel with a lower calorific value such as one of ethylene, natural or town gas, butane or propane as these provide a lower temperature flame than acetylene and butane is particularly preferred as it gives a stable easily controllable flame and is considered safer than acetylene if powders containing copper compounds are used. It is generally accepted that oxy-acetylene flames have temperatures of 2000 °C and more. It is preferred in accordance with an

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embodiment of the present invention if the flame of the flame spraying gun 12 imparts a temperature only sufficient to just melt the powder to be sprayed. Temperatures of 1500 °C or less and preferably 1200 °C or less are preferred and temperatures between 600 and 1000 °C may be more preferable. These low flame temperatures minimise decomposition of the ceramic powder components during flame spraying. Moreover, they limit the impact of evaporation of the materials to be flame sprayed and allow a deposition efficiency of more than 80%, i.e. more than 80% of the solid mass originally introduced into the gun 12, becomes attached to the substrate 19. Surprisingly mechanically stable, scratch resistant flame sprayed coatings are produced with these low temperatures.

10 The gun 12 is preferably held at 7 to 15 cm from the substrate 19 to be coated but this depends upon the size of the flame.

15 The material of substrate 19 preferably has a high melt temperature and a high thermal conductivity and when the substrate 19 is to be used as a target for a sputtering magnetron a good electrical conductivity is preferable. It is also preferred if the thermal expansion of the substrate material is similar to that of the ceramic coating to be applied. In accordance with embodiments of the present invention low temperature flame spraying and/or intense cooling of the substrate 19 allows the use of substrates 19 with a thermal expansion coefficient up to at least twice or down to at least a half of the thermal expansion coefficient of the ceramic coating. A non-limiting list of suitable materials may 20 be steel, iron, stainless steel, copper or copper alloys, however the low temperature flame spraying process in accordance with the present invention, either independently or in combination with intense cryogenic cooling of the substrate 19, allows other materials to be used such as paper, cardboard or polymeric materials. Preferably, the substrate 19 should be free of grease and dry before deposition. Preferably, the outer surface of metals 25 is sand blasted and then lapped with abrasive materials.

Where the substrate 19 is rigid it may be mounted in a suitable jig. For example, a cylindrical substrate 19 is preferably mounted in a rotating device such as a lathe. The substrate 19 may be held by rotatable chucks at each end thereof. The temperature of the solidified flame sprayed coating 40 on the surface of the substrate 19 is preferably 30 measured by a temperature sensor 13, 15. The sensor head 13 is preferably a remote sensing optical head which is not in contact with the surface 40 of the flame sprayed coating. The temperature to be measured is of the solidified coating 40 and not that of the

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coating immediately on impacting the substrate 19 which may have a higher temperature. Hence, the temperature sensor 13 is preferably mounted so that it lags behind the impact position of the flame sprayed materials a little. In addition a temperature sensor 31 may be provided inside the substrate 19 for further control of the deposition process.

5 In accordance with one embodiment of the present invention a means for intense cooling of the substrate 19 is provided. This is preferably a cryogenic cooler comprising a supply 16 of cryogenic fluid and a delivery system 11, 14, 17, 29, 30. The delivery system may be adapted to the form of the substrate 19. For example, for a cylindrical substrate 19 the cooling device may be a conduit 17 for supplying the cryogenic fluid to a control valve 11, a conduit 30 with regularly spaced holes 29 for distribution of the cryogenic fluid inside the substrate 19 and a control device 14 for receiving the output of the temperature sensor 13, 15 and for controlling the operation of the control valve 11 so as to maintain the surface temperature of the solidified coating 40 to within a certain range. Particularly preferred is a temperature range from room temperature (25 to 30°C) to 150

10 °C and more preferably room temperature to 100 °C. These low temperatures avoid thermal stresses between the coating 40 and the substrate 19 providing a good bond and good coating density, hardness and scratch resistance thus helping to ensure the long term stability of such a coating. Using a cryogenic fluid such as liquid nitrogen (77 °K) is quite advantageous and economical as it does not require the complication of perfectly sealed

15 rotating inlets and outlets to the substrate 19 when water or other liquid coolants are used. Additionally, cryogenic fluids such as liquid nitrogen produce large temperature gradients, thus increasing the thermal sink-effect.

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The cylindrical substrate 19 may be sealed by a seal 26 at one end and with a rotating seal 28 at the other. The seal 28 may be provided with a sealed feedthrough 27 for the supply of cryogenic fluid. However, in accordance with an embodiment of the present invention it is preferred if the ends 26, 27 allow escape of the cryogenic fluid which then forms a shield gas around substrate 19 during the flame spraying process. Particularly preferred cryogenic fluids are liquid nitrogen, liquid oxygen and liquid air. With some complex ceramic materials, one or more components may be reduced in the

25 flame spraying process. For such materials it may be advantageous to use a shield gas including oxygen, e.g. liquid air or liquid oxygen, which may help to reoxidise the reduced component. On the other hand with other complex ceramics it may be

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advantageous to reduce the contact time with oxygen at high temperatures, under which conditions liquid nitrogen would be preferred.

It is preferred if the deposition rate is selected in order to maintain the substrate surface temperatures mentioned above. Assuming the cylindrical substrate as shown in

5 Fig. 1, the rotation speed of the substrate 19, the linear speed of the gun 12 and the rate of material exiting the gun 12 may be controlled to achieve the temperatures specified above. For instance it has been found that when using cylindrical substrates made of stainless steel of 15 cm diameter and up to 40 cm long, a powder delivery of 5-10 g/min was suitable to produce 3 mm coatings when using a YBa<sub>2</sub>Cu<sub>3</sub>O<sub>x</sub> superconducting  
10 powder. The rotational speed of the substrate 19 may be in the range 10 to 100 RPM and the longitudinal feed of the gun 12 in the range 1 to 3 m/min. The deposition rate per reciprocating pass of the gun 12 was 10 to 50 micron thickness of the coating. About 10% of the deposited coating had maintained the lattice structure of the powder and exhibited superconducting properties. It will be appreciated by the skilled person that  
15 increasing the deposition speed, deposition thickness per pass or the flame temperature or reducing the thermal conductivity of the substrate material will increase the thermal load on the cooling system and adjustments of one or more of these parameters may be necessary to obtain satisfactory coatings.

It is preferably to control the atmosphere in the vicinity of the substrate 19 during  
20 coating deposition to prevent the presence of excessive water vapour and in particular to prevent condensation of water on the substrate 19. This may be achieved by generally air conditioning the air around the substrate 19 to reduce its dew point.

Fig. 2 is a schematic representation of a further embodiment of the flame spraying process and apparatus in accordance with the present invention. Components in Fig. 2 with the same reference numbers as in Fig. 1 refer to equivalent items. The substrate 19 in accordance with this embodiment is a foil or sheet of metal, plastic or other flexible material which is wound from a pay-off spool 32 to a take-up spool 36. Where the final coating 40 cannot be spooled, the foil with coating 14 may be drawn linearly from the pay-off spool 32 and cut into lengths. The coating 40, which may be a superconducting  
25 layer, is flame sprayed with a flame spray gun 12 similar to the one described with respect to Fig. 1. In particular it is preferable to use a fuel with a lower calorific value than acetylene such as natural or town gas, butane or propane. Preferably, the temperature of  
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the flame of the gun 12 imparts a temperature of 1500 °C or less, more preferably 1200 °C or less to the material being sprayed through the flame. This material may be in the form of powder either of finished components of the coating 40, e.g. oxides, or precursors thereof, e.g. nitrates, or may be in the form of a slurry of powders, e.g. oxides,

5 or a solution, e.g. of nitrates. Gun 12 may be controlled by hand or more preferably by a robot to provide zigzag motions across the width of foil 19 thus applying an even coating 40. Preferably a layer of 10 to 50 micron thickness is applied in each pass.

The temperature of the coating 40 may be monitored by one or more optical sensors 13, 15. The temperature of the foil 19 is regulated by means of a cryogenic fluid supplied from a container 16 to a series of holes or jets 29 via conduit 17, a controllable valve 11 and a conduit 30. The valve 11 is controlled by a controller 14 to maintain the temperature of the foil as determined by the sensor 13, 15 to less than 400 °C, preferably less than 150 °C and most preferably between 50 and 100 °C. Such low temperatures allow a wide range of materials for substrate 19 including polymeric materials, cellulosic materials as well as metals. Although only one controller 14 is shown the present invention includes several controllers each with its own controllable cryogenic cooling device 11, 29, 30 for individually controlling the temperature of different parts of the foil 19 or coating 40. Optionally, an optical encoder 34 may be attached to a roller 35. The optical encoder may be read with an optical sensor 37, 38, the pulse frequency generated in the sensor 37, 38 being proportional to the linear speed of the foil 19. This value may also be used by the controller 14 to control the complete process to maintain the temperatures and coating thicknesses mentioned above.

When producing superconducting coatings 40, it is preferred if there is no condensation of water onto the coating 40 nor onto the foil 19 so it is preferred if the atmosphere around the deposition equipment is air conditioned to reduce the dew point to below ambient temperature. Preferably the coated substrates in accordance with this invention are preferably stored for long periods in a plastic bag filled with a dry inert gas such as dry nitrogen. One aspect of the present invention is the flame spraying of powders which already have superconducting properties in the powder form. Using the methods in accordance with the present invention it is possible to flame spray such coatings and retain about 10% of the coating 40 produced without special heat treatments.

The superconducting and/or ceramic powder and/or metallic powder to be used

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for flame spraying is preferably homogeneous, exhibits the appropriate rheological properties and correct stoichiometry to generate the required properties in the final coating. Typical preferred densities for superconducting powders may lie in the range 4 to 5 g/cm<sup>3</sup>. A non-limiting list of suitable materials which may be flame sprayed as powders,

5 slurries or liquid solutions in accordance with the present invention are: superconducting materials such as R<sub>x</sub>Ba<sub>2</sub>Cu<sub>3</sub>O<sub>y</sub> where R is Y, La, Nd, Sm, Eu, Gd, Dy, Ho, Er, Tm, Yb, Lu; or

Bi<sub>2-x</sub>Pb<sub>x</sub>Sr<sub>2</sub>Ca<sub>n-1</sub>Cu<sub>n</sub>O<sub>y</sub>, Tl<sub>2</sub>Ba<sub>2</sub>Ca<sub>n-1</sub>Cu<sub>n</sub>O<sub>2n+3</sub>, HgBa<sub>2</sub>Ca<sub>n-1</sub>Cu<sub>n</sub>O<sub>2n+2+δ</sub>; or Ba<sub>2</sub>Ca<sub>n-1</sub>O<sub>2n+2</sub>, or CaBa<sub>2</sub>Ca<sub>n-1</sub>Cu<sub>n</sub>O<sub>2n+6</sub>; or cuprate high temperature superconductors of the general formula

10 A<sub>m</sub>E<sub>2</sub>R<sub>n-1</sub>Cu<sub>n</sub>O<sub>2n+m+2</sub> where A, E, R are selected from various cations such as A = Bi, Tl, Hg, Pb, Cu or a lanthanide element, E = Ba or Sr and R = Ca or rare earth element; or piezo-electric ceramics, for example, with the general formula M(Zr<sub>x</sub>Ti<sub>1-x</sub>)O<sub>3</sub> where M = Pb, Ba or Sr; or refractory ceramic oxides, nitrides, carbides or phosphates, e.g. Al<sub>2</sub>O<sub>3</sub>, MgO, Zr<sub>x</sub>O<sub>y</sub>; or metals and their alloys.

15 In accordance with a further embodiment of the present invention a method is provided for production of suitable ceramic powders. By starting from aqueous solutions containing the salts of the metals in the correct proportions a reactive precursor powder can be obtained using commercially available spray drying equipment in batches of kilograms. The type of salt (mostly nitrates) should preferably be compatible with thermal

20 decomposition to oxides in further processes such as sintering or flame spraying. In accordance with the present invention spray dried nitrate powders may be flame sprayed directly or the powders may first be sintered and then flame sprayed.

A spray drying system 50 in accordance with an embodiment of the present invention for the delivery of powder suitable for subsequent flame spraying is shown schematically in Fig. 3. The input liquid is drawn from a suitable source 53 via a peristaltic pump 54 to a spray head 71. Pressurised air 51 is drawn in through an air dryer and optional pre-heater 52 to the spray head 71 by a suction device such as a fan 63 at the end of the generally closed system. The liquid from source 53 enters the spray head 71 which is cooled by any suitable means 55 to prevent clogging due to early evaporation of the liquid. The liquid is atomised in a co-current two fluid nozzle 71 by the dry pressurised air 51 and discharged it into a chamber 56 where it dries to a powder. The liquid from source 53 may be a solution of suitable nitrates or a slurry of the relevant

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oxides with the addition of other agents such as binders.

Air 65 is drawn in by fan 63 over a heater 64 and introduced into chamber 56 via a ring orifice 72 which surrounds the outlet of the spray head 71. The air 65 also heats the spray head 71. The circumferential air flow 65 guides the evaporating liquid in chamber 56 and helps to prevent the powder sticking to the walls of the chamber 56. The air throughput of fan 63 is chosen so that powder of the correct grain size is swept from chamber 36 through an optional heater section 58 into a powder collector 59. Heavier particles settle out in trap 57 and are removed from the bottom of chamber 56.

The powder collector 59 may be any suitable device such as a cyclone, a bag filter or an electrostatic filter although a cyclone is preferred. The cyclone discharges the powder into a removable container 60 sealed to the bottom of the cyclone 59. Spent air is removed via the trap 61 and scrubbed in scrubber 12 to remove impurities. The final clean air is exhausted to atmosphere by the fan 63 which controls air flow through the system.

The control system 66 - 70 for the process functions as follows. The rotational speed of the centrifugal air pump 53, the temperature of the heating element 64 and the flow of the atomised air are set with controller 67, 70. Air flow is measured by gauge 68. The temperature of the hot air 65 and the air in the tube leading from the chamber 56 to the optional heater 58 is monitored using thermocouples 66, whereas final powder temperature is monitored by temperature sensor 69.

After spray drying, the powder may be sintered in a single step. For example, to produce a superconducting powder of the general formula  $YBa_2Cu_3O_x$ , with optional Ag, the required nitrates are dissolved in water in the correct stoichiometric proportions and spray dried as indicated above. The nitrates are then reduced to oxides by sintering at 920 - 960 °C for 40 to 60 hours. Optionally the nitrates may first be reduced by heating in air at 780 °C for 10 hours before sintering at the above temperatures and times. The  $YBa_2Cu_3O_x$  powder produced by this procedure is superconducting. An aspect of the present invention is to produce powders with superconducting properties by spray drying and optional sintering and then to flame spray these superconductive powders at the lowest flame temperatures necessary to obtain melting of the powder and coating formation on the substrate while cooling the coating in the fastest possible way. By this procedure the crystal structure present in the superconducting powder is disturbed as little as possible by the flame spraying process. Of course, melting the powder during

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flame spraying causes complete loss of crystal organisation if the time in the melt is long.

By lowering the flame temperature and shortening the time in the melt phase by cooling the coating very rapidly in accordance with the present invention, some local crystal organisation is kept in the final flame sprayed coating, e.g. about 10% of the final coating is in the superconducting phase, thus providing a coating on the substrate with an optimum starting condition for further heat processing to develop full superconducting properties. The addition of the metallic silver enhances the thermal and mechanical properties in later flame spraying and magnetron sputtering.

Alternatively, the powder for flame spraying may be spray dried from slurries of the relevant oxides in the correct stoichiometric proportions with the optional addition of silver in the above apparatus in accordance with the present invention. For instance, in the manufacture of a ceramic material the mixture of oxides may be produced by individually sieving them to 40 micron and then mixing in the correct proportions to obtain the stoichiometric proportions in the final coating. A quantity of deionised water is added of about 60% by weight of the powder as well as a quantity of an organic binder such as PVA (polyvinyl acetate) equal to about 2% by weight of the powder and then mixed into a slurry. The slurry is then spray dried as described above resulting in powder with a grain size from 30 to 50 micron. Generally, spray dried oxide slurries do not require sintering before flame spraying. The organic binder may be burnt out during flame spraying or in a special sintering step.

Spray drying of 10% by weight nitrate solutions generally produce grain sizes of 3 micron on average with at least 90% of the grains between 0.5 and 5 microns. In order to obtain the required grain size it is preferable to sinter as mentioned above. Light grinding and sieving of this sintered powder may produce a mass fraction of more than 80% with grain sizes between 40 and 80 micron. By the variation of appropriate concentrations of the solution of the aqueous media 53, and/or the addition of binders and/or the spray drying of slurries rather than solutions, allows control of the grain size in the final powder to between 2 and 100 microns. For example, the present invention includes the addition of organic binders such as polyvinyl acetate (PVA) to the liquid to be spray dried to control grain size in the final powder. Such binders may be burnt out in a later high temperature process such as sintering. An average grain size of 40 to 80 microns is preferred for good flame spray deposition. The final powder may be lightly milled and

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sieved to be improve the homogeneity of grain sizes.

One aspect of the present invention is the inclusion of silver metal in the final superconducting ceramic coating. This is achieved as mentioned above by inclusion of about 20% by weight of the ceramic materials of silver nitrate when nitrate solutions are spray dried and the flame sprayed or by addition of  $\text{Ag}_2\text{O}$  powder in an oxide slurry which is then spray dried and flame sprayed. The addition of silver in the flame sprayed material is beneficial for the inter-grain adhesion and heat dispersal during flame spraying thus yielding a strong and dense coating. The silver improves the thermal and electrical conductivity of the flame sprayed coating which is beneficial to the sputtering process when the substrate is used as a sputtering target. The improved conductivities allow higher power throughput for the magnetron than targets not containing silver.

The flame spraying process in accordance with the present invention allows the reconditioning of targets for sputtering magnetrons. It is well known that the presence of a static race-track plasma on a magnetron target during sputtering results in an erosion groove and poor target utilisation. Using the flame spraying process of the present invention such a worn target may be reconditioned by spraying the appropriate target material into the erosion groove and building up the target to its former thickness in these regions. By providing the intensive cryogenic cooling described above, the general target temperature may be kept below 400 °C, preferably below 150°C and most preferably between room temperature (~25°C) and 100°C. These low temperatures result in little damage to the existing target material while still providing a mechanically strong coating in the old erosion grooves. Such a process is particularly economic when the target material is expensive such as superconducting materials. The flame spraying gun 12 described above may be hand held and the contour of the erosion groove in the used target followed building up the lost material slowly, preferably 10 to 50 micron per pass. Preferably the gun 12 is controlled by a robot which is programmed to execute the correct motions with the gun 12 to fill up the erosion groove in the target.

While the invention has been shown and described with reference to preferred embodiments, it will be understood by those skilled in the art that various changes or modifications in form and detail may be made without departing from the scope and spirit of this invention as defined in the attached claims.

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**CLAIMS**

1. A flame spraying apparatus for spraying materials onto a substrate to produce a coating thereon, comprising:
  - 5 a burner for producing a flame;
  - an inlet for feeding the material to be sprayed through the flame, the flame imparting a temperature to the material to be sprayed of 1500°C or less, preferably 1200°C or less.
2. A flame spraying apparatus for spraying materials onto a substrate to produce a coating
  - 10 thereon, comprising:
    - a flame spraying gun; and
    - 15 a cooling system for the substrate, the cooling system including a device for bringing a cryogenic fluid into contact with the substrate.
  3. A flame spraying apparatus according to claim 2, wherein the flame of the flame spray gun imparts a temperature to the material to be sprayed of 1500°C or less, preferably 1200°C or less.
  4. A flame spraying apparatus according to any of claims 1 to 3, wherein the material to be
    - 20 flame sprayed is a powder, further comprising a spray drier for drying a precursor liquid to the powder.
  5. A flame spraying apparatus according to any previous claim, further comprising a sputtering magnetron for sputtering a further coating onto a further substrate, wherein the
    - 25 flame sprayed substrate is a target for the magnetron sputtering device.
  6. A method of flame spraying materials onto a substrate to produce a coating thereon, comprising:
    - generating a flame;
    - 30 feeding the material to be sprayed through the flame, the flame imparting a temperature to the material to be sprayed of 1500°C or less, preferably 1200°C or less.

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7. A method of flame spraying materials onto a substrate to produce a coating thereon, comprising:  
generating a flame for spraying the materials; and  
cooling the substrate by bringing a cryogenic fluid into contact with the substrate.
- 5
8. A method of flame spraying a superconducting ceramic material or a precursor thereof onto a substrate to produce a coating thereon, comprising:  
generating a flame for spraying the ceramic material;  
depositing the coating on the substrate; and
- 10 during deposition of the coating, cooling the substrate so that the solidified coating thereon has a temperature between 25°C and 150°C, preferably 25°C and 100°C.
- 15
9. A method of flame spraying according to claim 7 or 8, wherein the flame imparts a temperature to the material to be sprayed of 1500°C or less, preferably 1200°C or less.
10. A method of flame spraying to any of claims 6 to 9, wherein the material to be flame sprayed is a powder, further comprising the step of spray drying a precursor liquid to a powder.
- 20
11. A method of flame spraying to any of the claims 6 to 10, wherein the flame sprayed substrate is a target for the magnetron sputtering device, further comprising the step of: sputtering a further coating onto a further substrate using the target.
12. A method of reconditioning a used target for a sputtering magnetron having an erosion groove in the target material, comprising the step of:  
flame spraying target material into the erosion groove.
- 25
13. A reconditioned target for a sputtering magnetron, comprising:  
an erosion groove in the target material; and  
target material flame sprayed into said groove to restore the thickness of the target material to that of the unused material.
- 30

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14. A flame spraying apparatus according to any of the claims 1 to 5, or a method according to any of the claims 6 to 12, or a target according to claim 13, wherein the material to be flame-sprayed is a powder, a liquid solution or a slurry.
15. A flame spraying apparatus according to any of the claims 1 to 5 or 14, or a method according to any of the claims 6 to 12 or 14, or a target according to claim 13 or 14, wherein the flame sprayed coating is a ceramic coating, in particular a superconducting ceramic coating.
16. A flame spraying apparatus according to any of the claims 1 to 5, or 13 to 15, or a method according to any of the claims 6 to 12 or 14 or 15, or a target according to claim 13, 14 or 15, wherein the material to be flame-sprayed is a powder having superconducting properties.

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## ABSTRACT

- A method and an apparatus for flame spraying materials onto a substrate to produce a  
5 coating thereon is described which involves generating a flame in a flame spraying gun (12); and feeding the material to be sprayed through the flame in the conventional way. The flame preferably imparts a temperature to the material to be sprayed of 1500°C or less, preferably 1200°C or less. Further, the apparatus preferably includes a cooler (16, 11, 29, 30) for cooling the substrate (19) by bringing a cryogenic fluid into contact with the substrate.  
10 Preferably the substrate is cooled so that the solidified coating (40) thereon has a temperature between 25°C and 150°C, preferably 25°C and 100°C.

The apparatus and method are particularly suitable for producing superconducting coatings.

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Fig. 1

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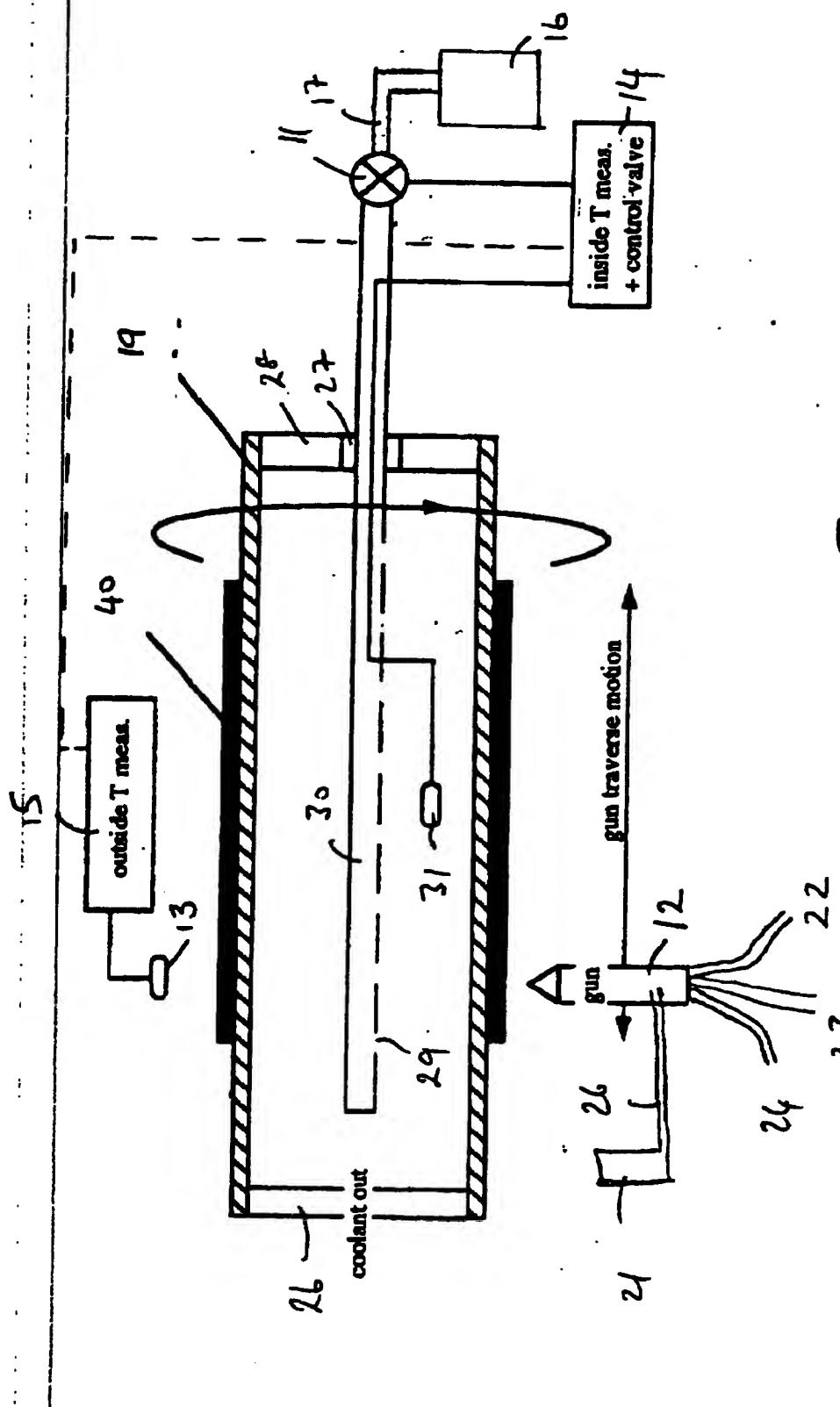
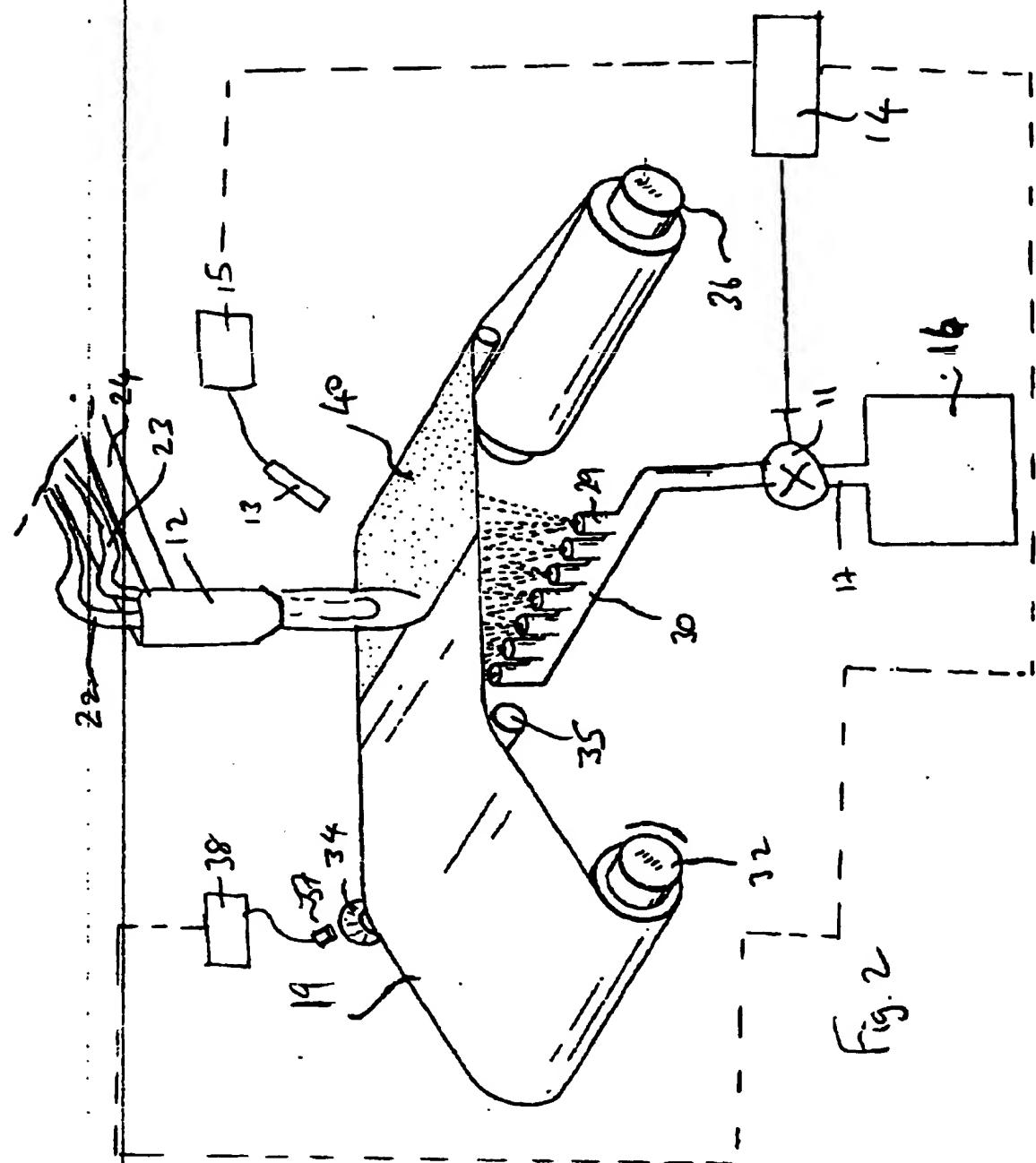


Fig. 1

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